Final Report

Sea Scallop Research

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Project Title:	**Tracking a large sea scallop recruitment event with high-resolution video survey in the Gulf of Maine**

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Amount: We were granted 32,700 lbs from the Delmarva Closed Area ($246,855) and 69,976 lbs from the Elephant Trunk Area ($528,318.80), totaling $775,173.80.

Introduction: The central banks and ledges of the Gulf of Maine have been important fishing grounds to the coastal communities of Maine, New Hampshire and Massachusetts for centuries (Rich 1929). Although historically known for groundfish (i.e. Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), silver hake (*Merluccius bilinearis*) and cusk (*Brosme brosme*), these areas have also been commercially fished for sea scallops (*Placopecten magellanicus*). The Gulf of Maine commercial scallop fishery now focuses on the inshore region and neither state nor federal surveys include the offshore banks and ledges; therefore little is known about the status of these scallop populations (Stokesbury et al. 2010).

The sea scallop fishery as a whole has grown from a low of 5,500 metric tons landed in 1998 to an average of 26,000 metric tons landed from 2003 to 2010, with high prices worth $455 million US in 2010 (NMFS, 2010; Voorhees and Pritchard, 2010; Figure 1). The overall scallop resource is above the estimated at maximum sustainable yield of 125,000 metric tons (NMFS, 2010).

There are three stocks in the US fishery, Georges Bank with 6,508 mt, Mid-Atlantic with 19,065 mt and the Gulf of Maine with 180 mt landings in 2010 (Figure 1). These 2010 landings for the Gulf of Maine are lower than in previous years, for example in the 1950's landings averaged 1,629 mt (Figure 2). Fippenies Ledge, Jeffreys Ledge and Cashes Ledge have all been closed since 2002 (Figure 3), while there has been little or no scallop fishing on Platts Bank since the early 1980s (Pers. comm. T. Nicholas).

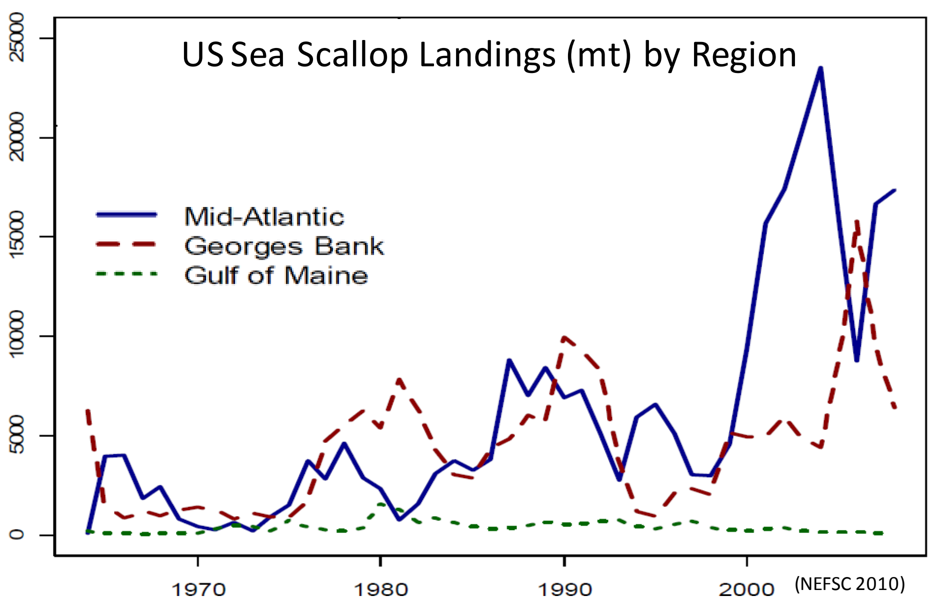

Figure 1. United States sea scallop landings from the mid 1960's to 2010 (Data source NEFSC 2010 50th Saw).

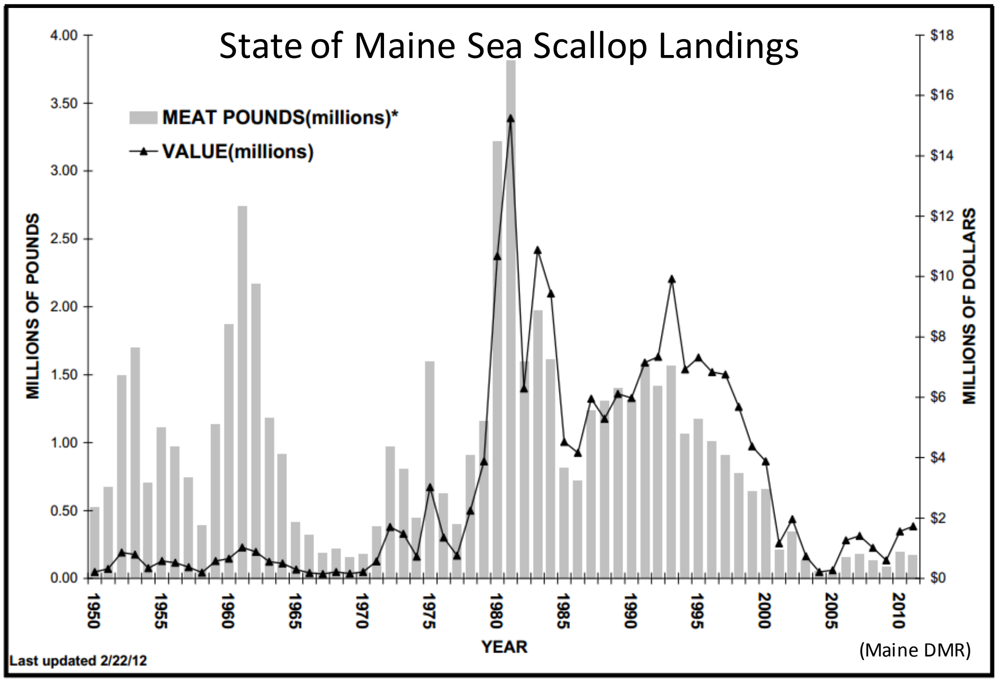

Figure 2. Scallop landings from the Gulf of Maine (Source Maine DMR).

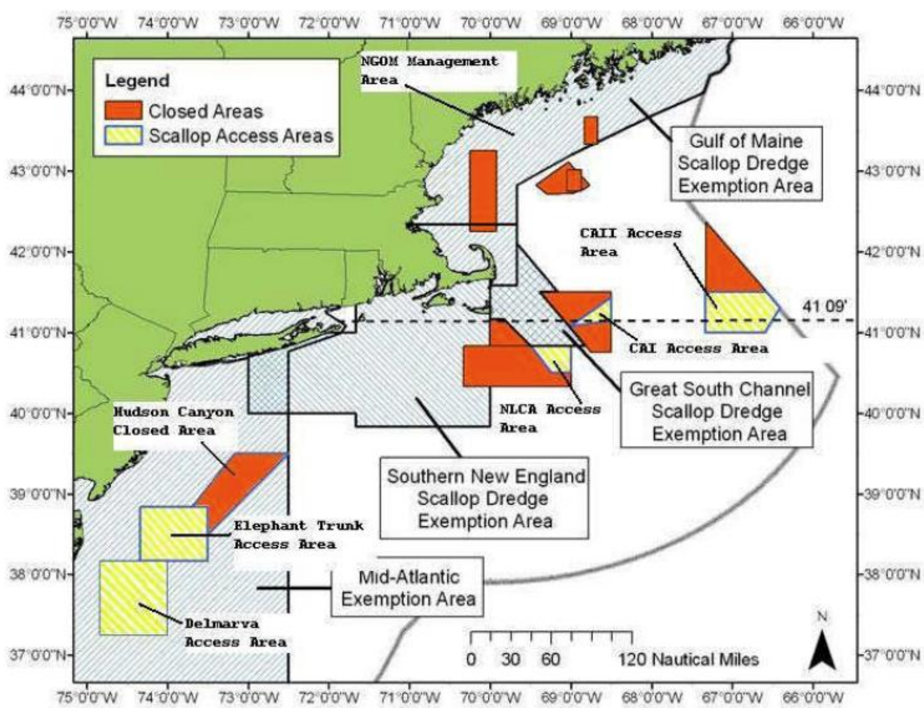

Figure 3. Scallop dredge exemption areas, access areas and closed areas (http://www.nero.noaa.gov/nero/fishermen/charts/scal1.html).

Proposed Work from the proposal:

Objectives:

In August 2009 we discovered large aggregations of pre-recruit (< 70 mm) juvenile scallops on Fippennies Ledge, Cashes Ledge, Platts Bank and Jeffreys Ledge with densities as high as 30 scallops·m^{-2}. We propose a high-resolution video survey to examine the abundance, spatial distribution and size composition of scallop aggregations in the Gulf of Maine and to assess rates of natural mortality, recruitment, local dissipation, and growth between 2009 and 2010.

Time Line:

The harvest trips were collected during the 2010 fishing year as the RFP required. We conduct the research cruise in August 2010 and supplied the data to the NEFMC and NMFS in the fall of 2010.

Methods:

Harvest trips to support the research:

The awarded lbs were divided into 11 compensation trips; two 16,350 lb trips in the Delmarva Area and nine 7,775 lb trips in the Elephant Trunk Area, which were completed by the end of the 2010 fishing year, February 28, 2011. Copies of the deposited checks are attached.

Research cruise and data processing:

All proposed field work was completed in August 2010. However, with the support of the scallop industry and a no-cost extension of the grant, we conducted an additional research cruise from 12 August to 16 August 2011.

We repeated the 2009 stations in 2010, and 2011; Platts Bank (43.166 N, 69.625 W) = 88 stations, Fippennies Ledge (42.783 N, 69.295 W) = 80 stations, Jeffreys Ledge (43.071 N, 70.049 W) = 50 stations and Cashes Ledge (42.915 N, 68.952 W) = 47, were surveyed in depths 10 to 100 m (Figure 4).

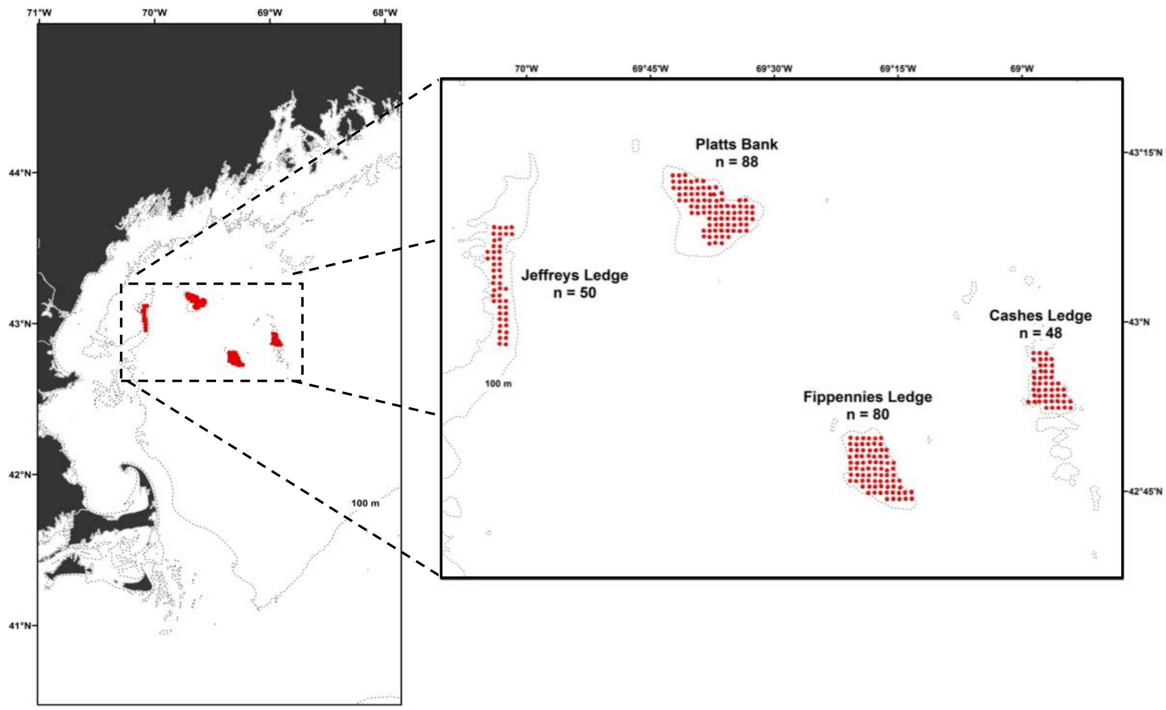

Figure 4. The station locations sampled with the SMAST video survey in 2009, 2010 and 2011 in the Gulf of Maine; stations are plotted on a 1 km grid.

A centric systematic sampling design was used to survey all four areas (Krebs 1999, Stokesbury 2002, Stokesbury et al. 2004). We deployed the SMAST video survey pyramid equipped with three DeepSea® Multi SeaCam video cameras (MSC-2060, DeepSea® Power and Light, San Diego, CA; Stokesbury 2002, Stokesbury et al. 2004) and an Ocean Imaging Systems® digital still camera (Nikon D80, DSC10000, Ocean Imaging Systems®, Falmouth, MA) on a 1-km station grid with 4 replicate quadrats sampled at each station. Only the camera mounted 700 mm above the sea floor providing a 0.60 m^2 quadrat was used, as it provides the best sample of small scallops. To account for partially visible scallops observed on the edge of the image, we calculated the quadrat size by adding half the mean shell height of scallops in the area surveyed to each edge of the quadrat (Stokesbury et al. 2004, NMFS 2010). Images of the sea floor were analyzed and the date, time, depth, latitude, longitude, substrate, macrobenthos and fish species were recorded for each quadrat. Scallop habitat was based on stubstrate type as observed in Stokesbury (2002) and Stokesbury et al (2004). All scallops were counted and their shell heights were measured with ImagePro Plus® image processing software.

Data Analysis

The video survey uses a two-stage sampling design in which four quadrats (elements) are sampled within each station (primary unit). Since there are a constant number of quadrats at every station, the two-stage mean number of scallops is calculated as:

(1) $$\bar{\bar{x}} = \sum_{i=1}^{n} \left(\frac{\bar{x}_i}{n} \right)$$ (1)

where:

n = the number of stations

$\bar{x}_i$ =the mean of the four quadrats at station i

The standard error of this two-stage mean is calculated as:

(2) $$SE(\bar{\bar{x}}) = \sqrt{\frac{1}{n}(s^2)}$$ (2)

where $s^2 = \sum (\bar{x}_i - \bar{\bar{x}})^2 / (n-1)$.

According to Cochran (1977) and Krebs (1999) this simplified version of the two-stage variance is appropriate when the ratio of sample area to survey area (*n/N*) is small. In this case, hundreds of m^2 (n) are sampled compared with millions of m^2 (N) in the survey areas. All calculations used scallops m^{-2}. Scallop density was estimated using only stations containing at least one scallop and the absolute number of scallops in each study area was calculated by multiplying scallop density by the total area containing scallops (Stokesbury 2002).

The spatial distribution of scallop density and size composition will be assessed by mapping these data in ArcGIS® software.

We attempted to use two methods to calculate instantaneous natural mortality (M) between 2009 and 2010 surveys. The first method used the ratio between the abundances (e.g. density) of clappers (D), shells of dead scallops still attached by the ligament, and live scallops (L) observed in the video survey, multiplied by the rate at which the shell ligament degrades (Dickie 1955, Merrill & Posgay 1964):

(2) $$M_c = \left(\frac{D}{L}\right)\left(\frac{52}{t}\right),$$

where 52 is the number of weeks in the year and t is the average number of weeks it takes for the two valves to separate, estimated as 33 weeks on Georges Bank (Merril & Posgay 1964). We could not use this method because very few clappers were observed.

The second method produces an annual estimate of instantaneous natural mortality (M_a), which is the difference between instantaneous total mortality (Z) and the instantaneous fishing mortality (F). The instantaneous total mortality (Z) of recruited scallops observed by the video survey was calculated using (Beverton & Holt 1957, Ricker 1975):

(3) $$Z = \ln\left(\frac{n_0}{n_1}\right) / \Delta t,$$

where n_0 is the number of scallops at the initial time (0) and n_1 is the number of scallops plus the growth increment estimated for the time (years) between subsequent surveys (Δt). However, as little recruitment was observed in 2010 and 2011 the growth increment estimate was not used.

Direct annual growth increments were examined rather than von Bertalanffy growth equations as the growth was somewhat sporadic between years. The Georges Bank shell height meat weight regression weighted for latitude and depth from SAW 50 was used to estimate total and exploitable biomass (NMFS 2010):

Meat weight = exp(9.6771 + 2.8387*ln(SH) -0.5084*ln(wt depth) - 4.7629*ln(wt latitude))

We assessed recruitment of scallops into the study areas by comparing the size frequency distributions sampled in 2009 and 2010.

Dissipation is a measure of how many scallops that settle at high densities spread out as they age. We assessed dissipation as a proportion of the scallops occurring at high densities relative to total scallop abundance in an area. We also examined changes in the index of dispersion, which is the ratio of the variance to the mean scallop densities.

Results

Due to slight variations in the number of stations and area covered between the 2009, 2010 and 2011 surveys, we spatially trimmed the data sets to make sample sizes similar and area surveyed comparable between years. Mean densities and standard errors were calculated to show trends from 2009 through 2011 (Table 1). Overall, we observed a trend of decreasing density with time (Table 1). We examined dissipation by comparing the index of dispersion ($s^2/\bar{x}$) between years. A value equal to 1 suggests a randomly distributed population, while anything greater than one indicates an aggregated distribution. While the scallops in the Gulf of Maine appeared to be highly aggregated, the decrease in index of dispersion from 2009 on indicates some degree of dissipation (Table 1).

Scallop meat weights were estimated using observed shell height frequencies and the Georges Bank shell height-meat weight relationship provided in SAW 50, as there is no relationship provided for Gulf of Maine scallops. Total scallop biomass was estimated by multiplying the mean scallop meat weight and the total abundance of scallops Exploitable biomass was estimated by applying the commercial dredge selectivity (Yochum and DuPaul, 2008) (Table 2).

Table 1. The number of stations, mean depth, mean number of scallops per square meter, standard error, percent coefficient of variation, index of dispersion and estimated total number of scallops for the four banks and ledges surveyed in 2009, 2010 and 2011.

Area	**Year**	**stations**	**Depth**	**per m2**	**SE**	**CV%**	**ID**	**millions of scallops**
Chases Ledge	2009	48	72.2	0.25	0.143	57.5	3.9	11.9
Fippennies	2009	79	73.1	2.19	0.385	17.6	5.4	173.0
Jeffreys	2009	48	53.3	0.88	0.223	25.4	2.7	42.0
Platts	2009	88	71.8	1.44	0.485	33.7	14.4	126.6
Total 2009								**353.5**
Chases Ledge	2010	47	78.6	0.17	0.117	69.9	3.8	7.8
Fippennies	2010	80	72.7	2.23	0.466	20.9	7.8	178.6
Jeffreys	2010	50	51.7	0.72	0.200	27.7	2.8	36.0
Platts	2010	88	72.6	0.68	0.219	32.4	6.2	59.5
Total 2010								**282.0**
Chases Ledge	2011	46	75.4	0.06	0.034	54.5	0.9	2.9
Fippennies	2011	66	72.3	1.28	0.338	26.4	5.9	84.5
Jeffreys	2011	50	54.5	0.48	0.131	27.2	1.8	24.0
Platts	2011	88	66.9	0.27	0.072	27.0	1.7	23.4
Total 2011								**134.8**

Table 2. Estimated mean total and exploitable biomass (mwt = meat weight; mill lbs = million pounds; mt = metric tons).

		Estimation of Total Biomass					Estimation of Exploitable Biomass			
Area	Year	mean mwt	mill lbs	in mt	SE		mean mwt	mill lbs	in mt	SE
Chases Ledge	2009	3.84	0.10	45.83	26.34		5.63	0.01	2.73	1.57
Fippennies	2009	2.03	0.78	351.90	61.93		9.94	0.06	26.40	4.64
Jeffreys	2009	3.88	0.36	163.10	41.48		7.39	0.03	12.51	3.18
Platts	2009	2.21	0.62	279.53	94.22		26.99	0.21	95.41	32.16
Total 2009			**1.85**	**840.35**				**0.30**	**137.05**	
Chases Ledge	2010	4.75	0.08	37.22	26.03		7.90	0.01	4.48	3.13
Fippennies	2010	2.26	0.89	403.10	84.06		12.63	0.09	41.00	8.55
Jeffreys	2010	4.32	0.34	155.64	43.17		9.64	0.04	18.18	5.04
Platts	2010	2.36	0.31	140.41	45.48		15.12	0.04	18.93	6.13
Total 2010			**1.62**	**736.38**				**0.18**	**82.59**	
Chases Ledge	2011	5.83	0.04	16.91	9.22		14.65	0.02	7.46	4.07
Fippennies	2011	4.66	0.87	393.76	103.81		8.55	0.10	46.42	12.24
Jeffreys	2011	13.62	0.72	326.88	88.99		21.57	0.40	181.71	49.47
Platts	2011	5.97	0.31	139.57	37.72		11.20	0.06	29.45	7.96
Total 2011			**1.93**	**877.12**				**0.58**	**265.05**	

Abundance, Dissipation, and Growth occurring at each area:

On Cashes Ledge the number of scallops decreased from 11.9 million in 2009 to 7.8 million in 2010 to 2.9 million in 2011 (Figure 5). This is a 34.2% and 63.0% decrease between 2009 and 2010, and 2010 and 2011, respectively. This represents a total instantaneous mortality rate of 0.419 between 2009 and 2010, and 0.994 between 2010 and 2011. Cashes Ledge is closed to fishing so this mortality represents only natural mortality. The mean shell height increased by 5.5 mm from 59.9 mm (n = 25) in 2009 to 65.4 mm in 2010. Only 7 scallops were measured in 2011 and 4 of these were small suggesting some minimal recruitment (Figure 5).

On Jefferys Ledge the number of scallops decreased from 42.0 million in 2009 to 36.1 million in 2010 to 24.0 million in 2011 (Figure 6). This is a 14.2% and 33.4% decrease between 2009 and 2010, and 2010 and 2011, respectively. This represents a total instantaneous mortality rate of 0.153 between 2009 and 2010, and 0.407 between 2010 and 2011. Jefferys Ledge is closed to fishing so this mortality represents only natural mortality. The mean shell height did not increase between 2009 and 2010, 55.4 mm (n = 101) and 56.7 mm (n = 86), respectively, but increased by 31 mm to 87.7 mm in 2011 (n = 59) (Figure 6).

On Fippennies Ledge the number of scallops decreased from 173.0 million in 2009 to 178.6 million in 2010 to 84.5 million in 2011 (Figure 7). This is a 100% survival between 2009 and 2010, and 52.7% decrease between 2010 and 2011. This represents a total instantaneous mortality rate of 0.0 between 2009 and 2010, and 0.748 between 2010 and 2011. Fippennies Ledge is closed to fishing so this mortality represents only natural mortality. The mean shell height increased by 1.8 mm from 46.9 mm (n = 364) in 2009 to 48.7 mm (n = 416) in 2010, and increased by 14.8 mm to 63.5 mm in 2011 (n = 212) (Figure 7).

On Platts Bank the number of scallops decreased from 126.6 million in 2009 to 59.5 million in 2010 to 23.4 million in 2011 (Figure 8). This is a 52.9% and 60.8% decrease between 2009 and 2010, and 2010 and 2011, respectively. This represents a total instantaneous mortality rate of 0.754 between 2009 and 2010, and 0.936 between 2010 and 2011. Platts Bank is partially open to fishing so this mortality represents possible fishing and natural mortality. The mean shell height increased by 5.0 mm from 45.3 mm (n = 245) in 2009 to 50.3 mm (n = 138) in 2010, and increased by 18.0 mm to 68.3 mm in 2011 (n = 58) (Figure 8).

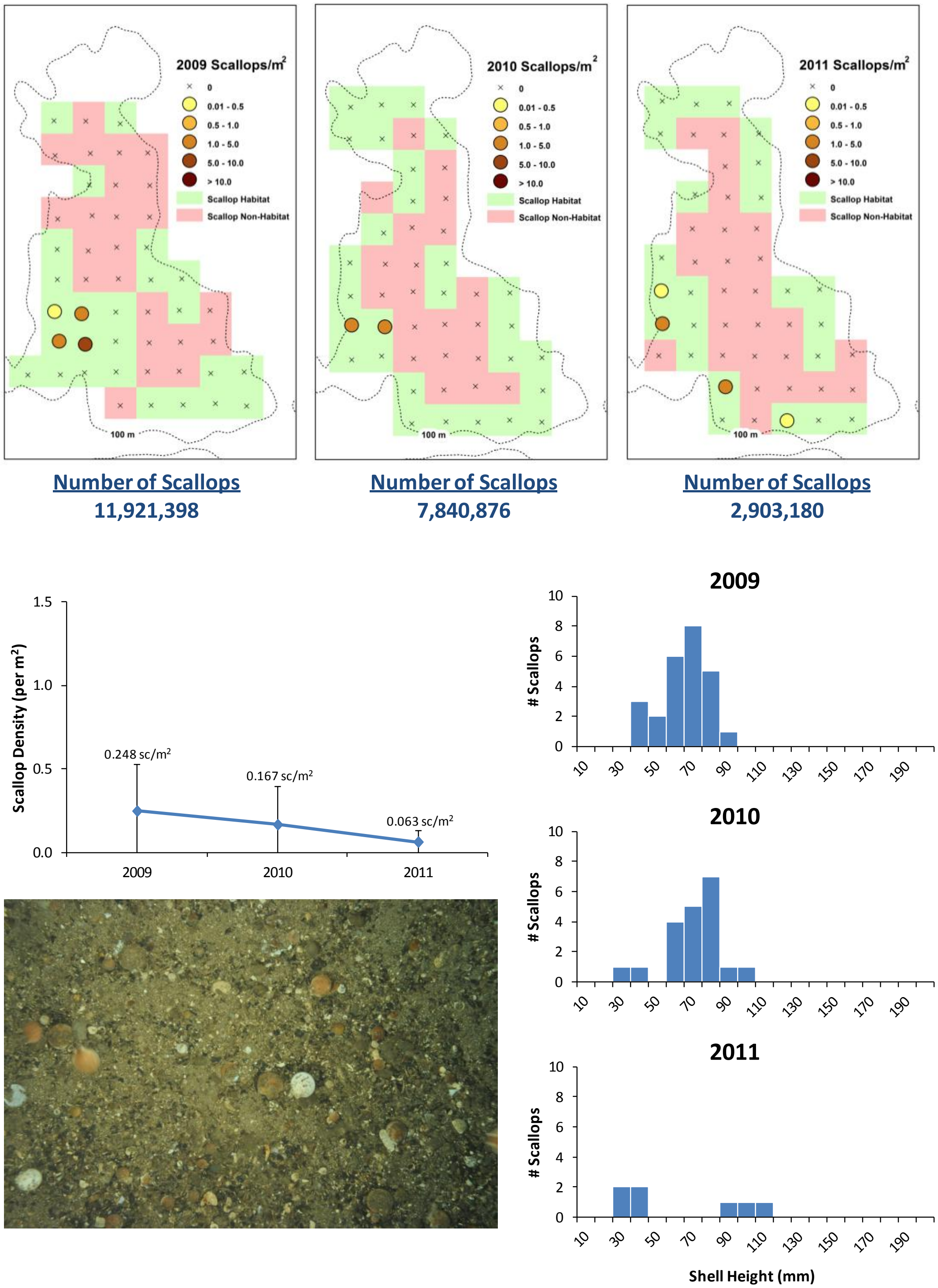

Figure 5. The distribution of sea scallops, substrate classified as potential scallop habitat and non-habitat, mean density m^2 and shell height frequencies (mm) observed on Cashes Ledge from 2009 to 2011.

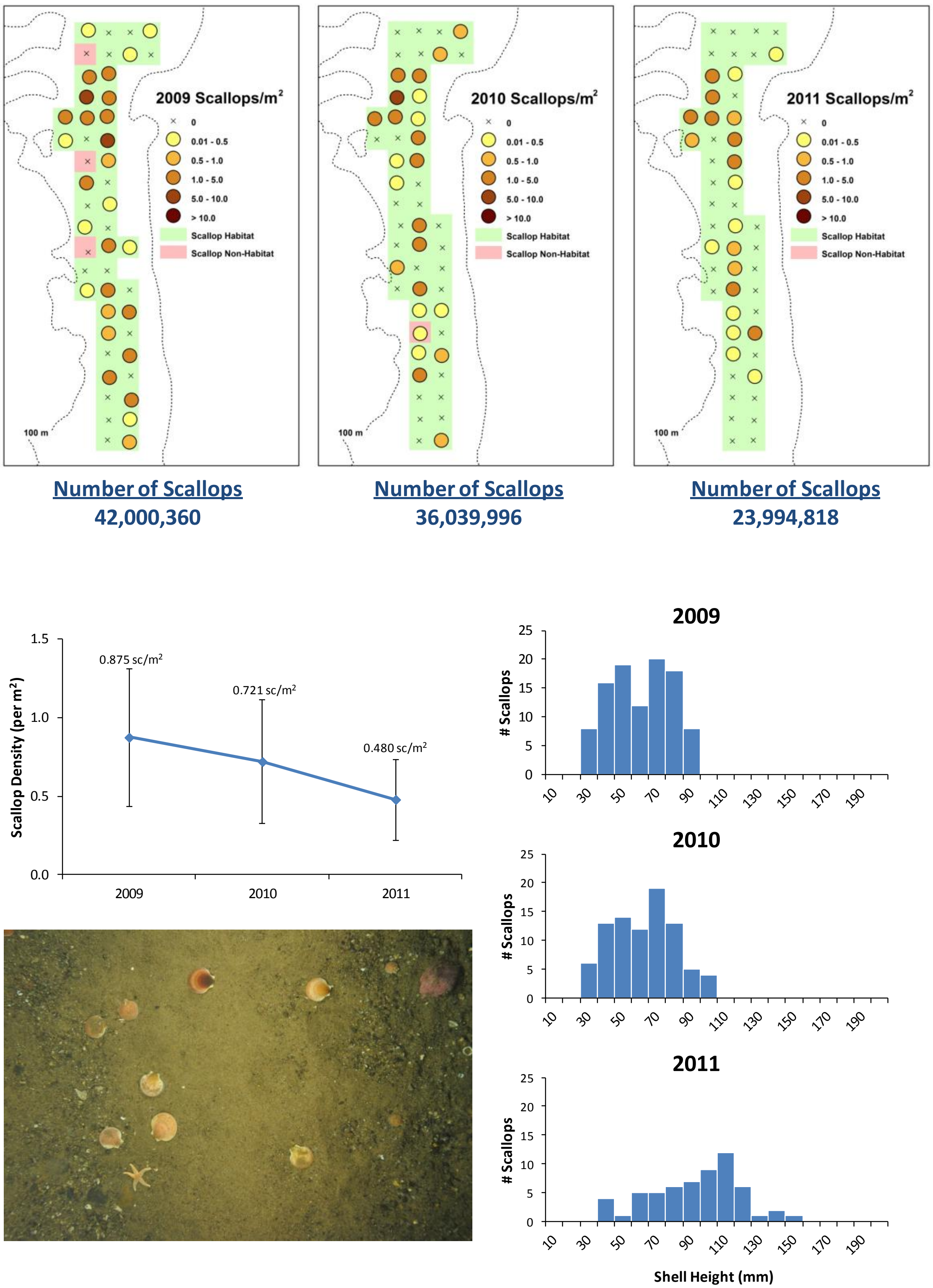

Figure 6. The distribution of sea scallops, substrate classified as potential scallop habitat and non-habitat, mean density m^2 and shell height frequencies (mm) observed on Jeffery's Ledge from 2009 to 2011.

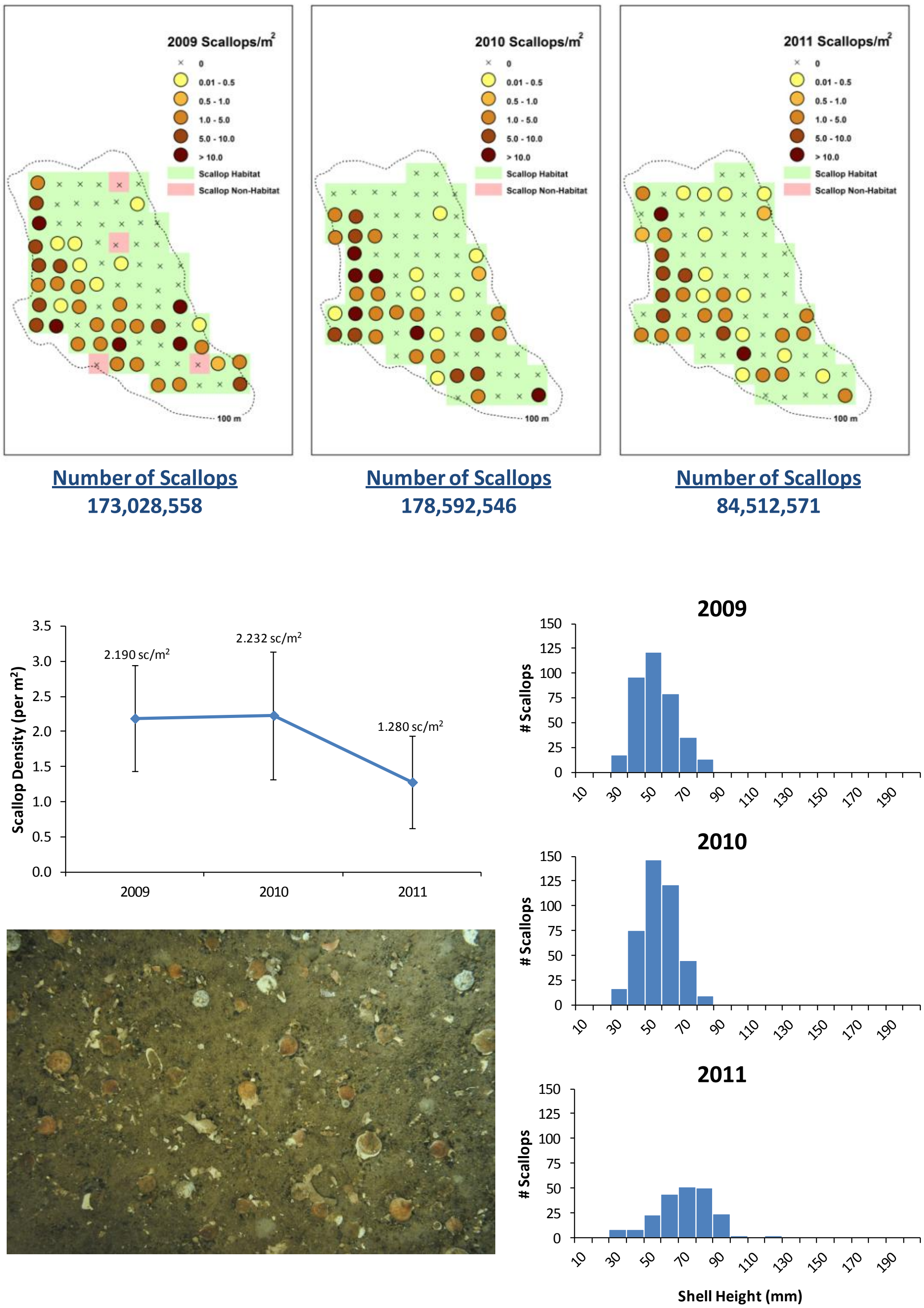

Figure 7. The distribution of sea scallops, substrate classified as potential scallop habitat and non-habitat, mean density m^2 and shell height frequencies (mm) observed on Fippennies Ledge from 2009 to 2011.

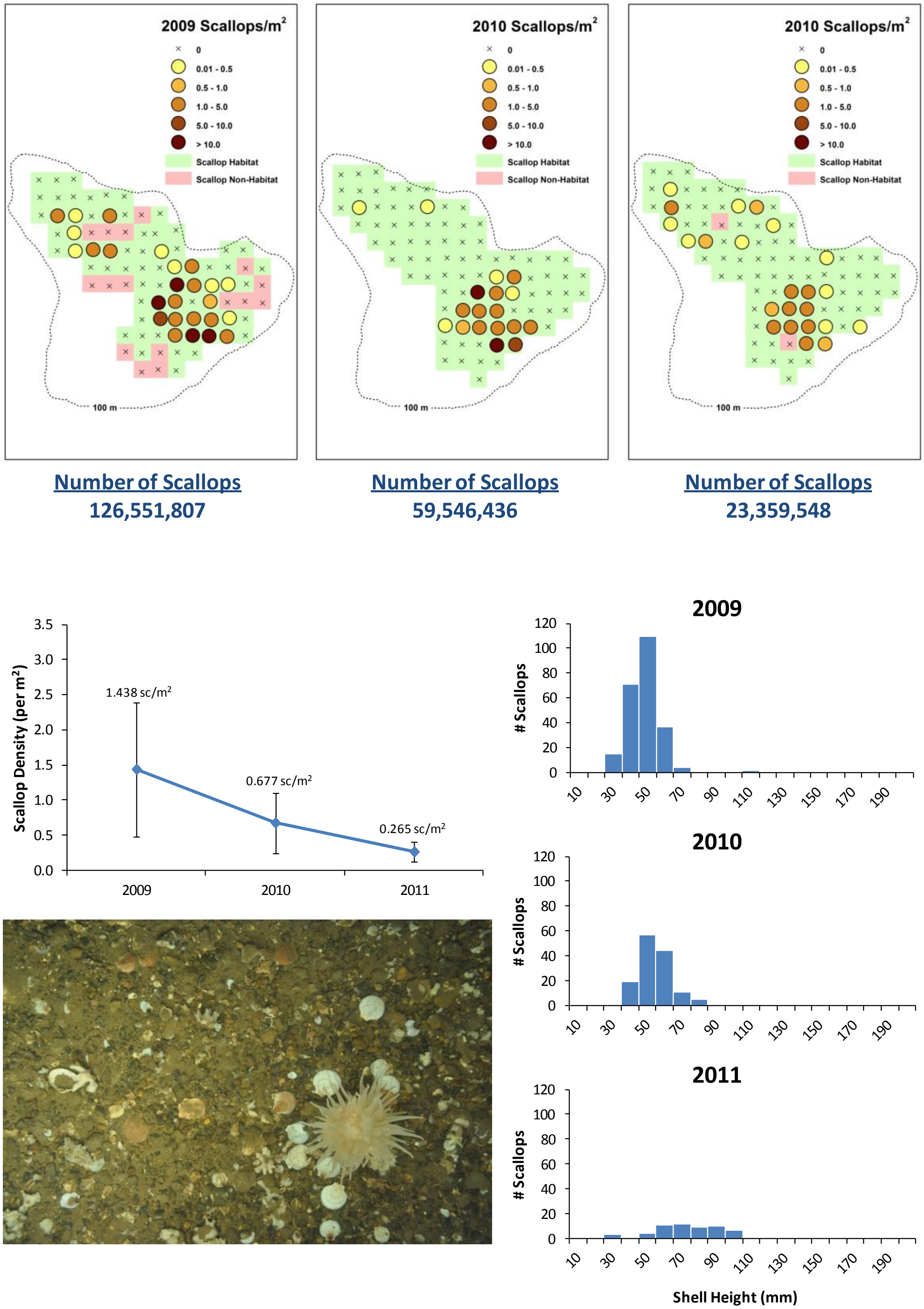

Figure 8. The distribution of sea scallops, substrate classified as potential scallop habitat and non-habitat, mean density m^2 and shell height frequencies (mm) observed on Platts Bank from 2009 to 2011.

Discussion:

Our 2009 video surveys to five banks and ledges in the Gulf of Maine revealed that Fippenies Ledge, Jeffreys Ledge, Cashes Ledge and Platts Bank all had high densities of small scallops consistent with a recent recruitment event. Using the small camera as the sampling quadrat there were 354 million scallops in 134 km^2 (using the DSC digital still camera there were 470 million scallops in 2009 as cited in Stokesbury et al. (2010), however this camera malfunctioned in 2010 so to keep the selectivity constant we used the small camera for these analysis). Fippenies Ledge and Platts Bank contained 45% and 38% of these scallops while Jeffreys Ledge and Cashes Ledge had 13% and 4% respectively. Survival of these scallops to harvestable size (~102 mm) will result in a significant increase in the offshore Gulf of Maine scallop resource. Assuming an adductor meat yield of 20 g, and ignoring mortality, this resource would produce a harvestable biomass of 9,400 mt worth approximately $US124 million (Stokesbury et al. 2010).

Repeating these surveys in 2010 and 2011 have revealed interesting patterns in scallop population dynamics. First the single strong recruitment in 2009 with a size range of about 25 to 75 (mm) was unique. There were very few larger scallops or small scallops observed in the three surveys. This suggests a sporadic recruitment pattern for these areas; when a recruitment event occurs it can be very large but it occurs infrequently.

Scallop natural mortality seems to have been relatively high on Cashes and Jeffrey's Ledges between 2009 and 2010. In contrast there was no mortality on Fippenies between 2009 and 2010 even thought the scallop densities were an order of a magnitude higher (2.19 scallop m^2 compared to 0.875 and 0.248 scallops m^2). The highest mortality occurred on Platts Bank between 2009 and 2010, however this could have been a combination of fishing and natural mortality. Growth for this year (2009 to 2010) was minimal in all areas ranging between 1.3 mm and 5.5 mm of increased shell height.

During the second year, between 2010 and 2011, mortality increased drastically in all areas ranging between 33.4% and 63.0%. There was no clear evidence that fishing mortality occurred on Platt's Bank as the instantaneous mortality rate was similar to both Cashes and Fippenies Ledges. Coupled with this increased mortality rate, the mean growth increments increased ranging between 14.8 and 31.0 mm of new shell (note Cashes ledge was not included due to small number of measured scallops in 2011). This suggests a relationship between density and growth rate. If this is the case it is location specific as densities and growth varied between areas.

The total number of scallops decreased by 26.1 % while the total biomass increased by 36.3% between 2009 and 2011. The mean shell height of 67.6 mm in 2011 is still far below the exploitable shell height of 102 mm. Overall scallop average shell height increased by 17 mm in two years and it will require several more years for these scallops to reach harvestable size.

Ongoing Research:

The 2009 Gulf of Maine SMAST video survey data was provided to the NEFSC Invertebrate working group for inclusion in the 50th SAW on 20 February 2010.

This research was presented at:

Carey JD, Stokesbury KDE. Tracking the Population Dynamics of a Large Sea Scallop Year Class in the Gulf of Maine. 104th National Shellfisheries Association Annual Meeting, Seattle, WA (March 25-29, 2012).

We are presently working on a primary publication from this research.

Further, data from the research conducted for this grant have been/or is being used in:

1) SASI: Sediment data from the 2009 and 2010 GOM surveys were included in the Swept Area Seabed Impacts Model used by the New England Fisheries Management Council in the most recent Habitat Omnibus Amendment (NEFMC 2010).

2) Cashes Ledge Habitat Assessment: B. Harris (Alaska Pacific Univ), J. Grabowski (Northeastern Univ) and C. McGonigle (Univ of Ulster) are using the 2009 and 2010 GOM survey video and imagery to refine earlier work done with multi-beam accoustics (McGonigal et al. 2011) including:

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